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Crop Residue Removal Effects on Corn Yield and Fertility of a Norfolk Sandy Loam

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ABSTRACT

To meet future demands, alternative energy sources will be needed because long-term energy problems have not been solved. Crop residue may provide a readily available on-farm bioenergy source, but effects of removing residue on soil fertility, water conservation, and crop production need further investigation. A 4-yr field experiment was conducted on a Norfolk sandy loam (Typic Paleudults) to determine the effects of removing crop residues on soil pH, extractable nutrient concentrations, and yield of corn (*Zea mays* L.). Four stover management treatments evaluated between 1979 and 1982 included conventional tillage with stover incorporated, and conservation tillage with 0, 66, or 90% of the stover removed. Treatments were split and evaluated with and without supplemental irrigation. Extractable nutrient concentrations were evaluated by comparing values obtained from an initial soil sampling with those of samples collected each fall thereafter. Ear leaf analyses were used to monitor treatment effects on plant nutrient status. Annual corn stover yields of 3 to 7 Mg ha^{-1} provided 5 to 11 $\times$ 10^7 kJ ha^{-1} of potential bioenergy without reducing winter surface cover below 80%. Harvesting corn residues increased annual N, P, and K removal by 26 to 57, 6 to 14, and 49 to 124 kg ha^{-1}, respectively. Soil extractable and plant nutrient concentrations indicated fertilization rates were adequate to compensate for nutrients removed with crop residues. Annual soil analyses showed that surface-applied lime and fertilizer were rapidly leached through low exchange capacity surface horizons, but accumulated in subsoil horizons even when conservation tillage practices were utilized. Irrigation, tillage, and residue management treatments resulted in few significant differences indicating that in this physiographic region, some crop residues could be utilized for bioenergy production. However, plant nutrients contained in those residues would have to be replaced by increased fertilization.

Additional Index Words: conservation tillage, minimum tillage, bioenergy source, nutrient distribution, nutrient balance, *Zea mays* L., *Secale cereale* L.

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CROP RESIDUE is often an asset because it helps control wind and water erosion (13, 25). However, excessive crop residue can also be a liability because of phytotoxicities, plant disease, and weed control problems associated with its management (6, 10, 29). Some crop residue has traditionally been harvested and used for animal feed and bedding, but nutrients and organic matter were generally recycled to the land via manure disposal. In the recent search for renewable alternatives to fossil fuels, attention has been directed toward using crop residue as an on-farm energy source. Unfortunately, this would generally not allow recycling of plant nutrients and organic matter.

Claar et al. (5) concluded that in Iowa sufficient corn (*Zea mays* L.) cobs were produced to dry corn grain by using a crop residue furnace, but drying costs would increase by 50% compared to purchasing liquid propane gas (LPG) at 1980 prices of $0.24/L. Lockeretz (20) concluded that the value of crop residues for ethanol production or boiler fuel was comparable to immediate and direct costs (collection and transportation) of residue removal, but it was not sufficient to compensate farmers or society for long-term benefits resulting from returning crop residues to the soil. He also emphasized the importance of coordinating soil conservation policies when developing public policy concerning renewable energy programs. Epstein et al. (11) emphasized that alternative uses for crop residues should be considered only when needs for soil protection and productivity have been met. Larson (18) concluded that removal of a portion of crop residues should not be objectionable to the agricultural community if soil productivity could be maintained.

The Atlantic Coastal Plain contains three interstate Major Land Resource Areas (MLRA's) which produce substantially more crop residue than is needed for controlling water erosion (1,3). Also, if improved water and nutrient management practices are adopted (16,24) and conservation tillage methods are practiced, corn residue production in this physiographic region may be sufficient to make residue harvesting economically feasible.

Recently, public interest in harvesting crop residues has declined because fossil fuel prices have decreased, but long-term energy problems have not been solved. Therefore, in MLRA's where sufficient crop residues are produced to control wind and water erosion, long-term effects of removing them on soil productivity and nutrient status must be quantified. Objectives of our research were (i) to quantitatively measure the amount of crop residue that could be collected and the amount of plant nutrients removed using standard farm equipment and (ii) to determine the effects of removing crop residues on root zone soil pH, plant and soil nutrient concentrations, and yield of corn grown with and without supplemental irrigation on a Typic Paleudults soil.

METHODS AND MATERIALS

A 2.65-ha field experiment was initiated in 1979 on a Norfolk (fine-loamy, siliceous, thermic, Typic Paleudults) sandy

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[3] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Dep. of Agric. or the S.C. Agric. Exp. Stn. and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

Table 1—Cultural practices used for corn production.

Year	Planting date	Water applied	Stand density	Dolomitic lime	Fertilization rate N	P	K	Mg	S	B	Zn
		mm	plant ha⁻¹	kg ha⁻¹							
1979	12 Apr.	0†	53 100	--	230	30	170	--	--	--	--
1979	12 Apr.	60	53 100	--	230	30	170	--	--	--	--
1980	1 May	0	47 400	--	230	30	170	--	--	--	--
1980	1 May	60	47 400	--	230	30	170	--	--	--	--
1981	10 Apr.	0	57 800	1 200‡	225	30	170	--	42	2.8	3.4
1981	10 Apr.	115	79 500	1 200‡	225	30	170	--	42	2.8	3.4
1982	9 Apr.	0	55 600	--	200	30	170	22	42	2.8	3.4
1982	9 Apr.	90	76 600		270	30	170	22	42	2.8	3.4

† Seasonal rainfall totaled 384, 234, 440, and 461 mm in 1979, 1980, 1981, and 1982, respectively.
‡ Lime provided approximately 250 and 140 kg ha⁻¹ of Ca and Mg, respectively.

Table 2—Dry matter and nutrients removed by harvesting corn stover from a Norfolk sandy loam.

Year	Removal rate	Irrig.	Dry matter	N	P	K	Ca	Mg	Mn	Zn
	%		Mg ha⁻¹	kg ha⁻¹						
1979	66	No	3.30	26	6	49	6	5	0.1	0.1
1979	90	No	5.00	39	10	74	8	7	0.2	0.2
1979	66	Yes	3.98	34	8	61	7	6	0.2	0.1
1979	90	Yes	6.03	52	12	93	11	9	0.2	0.2
1980	66	No	3.62	29	6	74	8	5	0.2	0.1
1980	90	No	5.27	43	10	106	10	7	0.3	0.2
1980	66	Yes	4.17	32	10	78	9	6	0.2	0.1
1980	90	Yes	6.46	46	14	116	12	9	0.2	0.2
1981	66	No	4.22	35	7	85	8	6	0.2	0.1
1981	90	No	6.40	57	12	124	12	9	0.3	0.2
1981	66	Yes	4.40	27	5	78	8	6	0.2	0.1
1981	90	Yes	6.66	41	7	111	13	10	0.3	0.2

loam. Corn was planted using a Brown-Harden Super Seeder[3]. This implement disrupts physical restrictions to rooting to a depth of approximately 45 cm below each row, but is defined as conservation tillage because it causes minimal disturbance to surface residues. Weeds were controlled with appropriate herbicides at recommended rates (30). An irrigation split was imposed during the first growing season by monitoring soil-water tension with tensiometers. When tensions exceeded 25 kPa at the 30-cm depth, supplemental water was applied to irrigated blocks using a traveling gun irrigation system. Planting dates, irrigation water, stand density, and fertilization rates are summarized in Table 1. Following grain harvest, four tillage/residue-removal treatments [(i) multiple disking with incorporation of residues, (ii) conservation tillage with no residues removed, (iii) conservation tillage with approximately 66% of the residues removed, and (iv) conservation tillage with greater than 90% of the residues removed] were initiated. These treatments were evaluated using a split plot design with five replications. Crop residues were removed by varying the cutting height of a flail-type forage harvester. A winter rye (*Secale cereale* L.) cover crop was planted between the 1979 and 1980 corn crops to increase annual biomass production. Rye was planted in October, grown without irrigation, and harvested in March at the boot stage of growth. Soil surface cover was measured periodically using the line-transect method (17).

Soil samples were collected from the Ap, E, and Bt horizons of each plot prior to planting corn in 1979 and each autumn thereafter. Samples were air dried, crushed, passed through a 2-mm sieve, and analyzed for pH and Mehlich no. 1 extractable P, K, Ca, Mg, Mn, and Zn (7).

Subsamples of crop residues were collected to determine water content and nutrient concentrations. Corn leaves were collected from opposite and below the primary ear at silking to assess nutrient levels within the crop. All plant samples were analyzed for N, P, and K after wet ashing with sulfuric and selenous acids. Secondary and micronutrient concentrations were measured in subsamples by the Univ. of Georgia or Clemson Agricultural Service Laboratories.

Corn grain yields were measured and adjusted to a moisture content of 15.5%. Data were analyzed statistically and interpreted using analysis of variance, least significant difference (LSD), or Duncan's multiple range test at $P(0.05)$.

RESULTS AND DISCUSSION

This research site lies within intrastate MLRA 133 which Campbell et al. (3) identified as an area where high amounts of residue were available for uses other than controlling soil erosion. Data in Table 2 show that in this study, 3.3 to 6.7 Mg ha^{-1} of corn stover could be harvested each year. In 1979, irrigation significantly increased maximum harvestable stover from 5.0 to 6.0 Mg ha^{-1} [LSD(0.05)$\geq$0.3], but it did not increase stover production in 1980 or 1981. By assuming a net heating value of 13.4 MJ kg^{-1} (5) for corn stover, the calculated potential bioenergy ranged from 5.5 to 11.2 $\times$ 10^{4} MJ ha^{-1} depending upon season, water management, and residue removal rate.

The potential for increasing on-farm bioenergy production by growing winter rye was also evaluated. Production of rye biomass following irrigated corn was significantly lower (975 vs. 1365 kg ha^{-1}) than production following nonirrigated corn. A lower residual soil-N concentration is assumed to have caused the growth difference although N, P, and K concentrations in the rye forage (data not shown) were similar and within normal sufficiency ranges (28).

Table 3—Influence of tillage, crop residue removal, and irrigation on yield of corn grown on a Norfolk sandy loam.

Tillage system	Residue harvested	Water management	Grain yield 1979	1980	1981	1982
	%		kg ha⁻¹			
Conventional	0	Nonirrigated	--	5 930 d	5 890 d	10 620 bcd
Conservation	0	Nonirrigated	8 280 b*	6 130 d	8 110 b	9 830 e
Conservation	66	Nonirrigated	--	5 930 d	7 570 bc	10 200 de
Conservation	90	Nonirrigated	--	6 090 d	7 230 c	10 350 cd
Conventional	0	Irrigated	--	8 260 a	10 690 a	11 340 a
Conservation	0	Irrigated	9 660 a†	6 930 c	10 470 a	10 820 abc
Conservation	66	Irrigated	--	7 200 bc	10 560 a	10 680 bcd
Conservation	90	Irrigated	--	7 590 b	10 680 a	10 900 ab

* Means within a column followed by the same letter are not significantly different at $P(0.05)$.
† The 1979 corn crop was planted into soybean and winter weed residues without prior surface tillage.

Table 4—Percentage of soil surface covered with corn stover one month after grain and stover harvest.

Tillage system	Residue harvested	Soil cover
	%	
Conventional	0	67
Conservation	0	95
Conservation	66	93
Conservation	90	83
LSD (0.05)		5

The rye forage had an average water content of 83% because it was harvested at an immature growth stage. Therefore, a low heating value of 3.74 MJ kg^{-1} (19) was used to estimate potential bioenergy. These calculations showed that 0.5 to 0.8 $\times 10^4$ MJ ha^{-1} could be produced, but this is relatively insignificant when compared to bioenergy from corn stover. Bioenergy production from winter rye could be increased significantly by delaying harvest until the crop was more mature (14), but this would delay planting of the corn crop and probably reduce grain and stover production in this physiographic region (30).

Growing a rye cover crop significantly reduced irrigated corn grain yields in 1980 (Table 3) because stand establishment was better where residues had been incorporated or removed. Therefore, following the 1980 and 1981 corn crops, rye was not grown.

Table 6—Nutrient status of Norfolk sandy loam after 2 and 4 yr of tillage and residue removal treatments.

Tillage system	Residue removed	Horizon depth	Sampled in	Water pH	Mehlich I extractable P	K	Ca	Mg	Mn	Zn
	%				mg kg^{-1}					
Conv.	0	Ap/0-5 cm	1980	5.8	62	94	275	37	13	4.8
Cons.	0	Ap/0-5 cm	1980	5.7	57	102	276	38	12	4.4
Cons.	66	Ap/0-5 cm	1980	5.7	54	95	333	43	14	4.3
Cons.	90	Ap/0-5 cm	1980	5.7	62	77	306	40	12	5.5
LSD (0.05)				NS	NS	NS	NS	NS	NS	NS
Conv.	0	Ap/0-5 cm	1982	5.5	64	129	301	51	11	5.1
Cons.	0	Ap/0-5 cm	1982	5.9	66	108	383	95	11	6.8
Cons.	66	Ap/0-5 cm	1982	5.8	70	108	419	93	14	6.9
Cons.	90	Ap/0-5 cm	1982	5.8	77	126	424	94	13	5.9
LSD (0.05)				0.2	NS	NS	82	17	3	1.5
Conv.	0	Ap/5-20 cm	1980	5.6	49	69	237	29	11	3.2
Cons.	0	Ap/5-20 cm	1980	5.5	46	53	238	26	12	2.1
Cons.	66	Ap/5-20 cm	1980	5.6	40	49	299	32	11	2.1
Cons.	90	Ap/5-20 cm	1980	5.6	45	44	264	27	10	1.8
LSD (0.05)				NS	NS	18	NS	NS	NS	0.9
Conv.	0	Ap/5-20 cm	1982	5.3	52	81	258	39	10	3.7
Cons.	0	Ap/5-20 cm	1982	5.3	49	74	228	34	9	3.6
Cons.	66	Ap/5-20 cm	1982	5.3	50	66	313	43	10	3.4
Cons.	90	Ap/5-20 cm	1982	5.4	52	76	297	37	10	3.7
LSD (0.05)				NS	NS	NS	NS	NS	NS	NS
Conv.	0	E/20-40 cm	1980	5.5	12	56	138	20	4	0.5
Cons.	0	E/20-40 cm	1980	5.3	12	46	147	22	3	0.7
Cons.	66	E/20-40 cm	1980	5.4	13	48	157	25	5	0.7
Cons.	90	E/20-40 cm	1980	5.5	12	42	145	22	4	0.4
LSD (0.05)				NS	NS	NS	NS	NS	NS	NS
Conv.	0	E/20-40 cm	1982	5.1	10	72	161	29	3	1.4
Cons.	0	E/20-40 cm	1982	5.2	14	71	152	28	3	1.0
Cons.	66	E/20-40 cm	1982	5.1	8	66	203	38	4	0.8
Cons.	90	E/20-40 cm	1982	5.2	11	59	204	33	5	1.6
LSD (0.05)				NS	NS	NS	NS	NS	NS	NS
Conv.	0	B/40-90 cm	1980	5.2	4	114	354	73	2	0.2
Cons.	0	B/40-90 cm	1980	5.0	4	104	305	59	1	0.6
Cons.	66	B/40-90 cm	1980	5.0	4	102	323	69	1	0.2
Cons.	90	B/40-90 cm	1980	5.1	3	110	340	70	1	0.2
LSD (0.05)				NS	NS	NS	NS	NS	NS	0.1
Conv.	0	B/40-90 cm	1982	5.0	3	133	397	88	1	0.4
Cons.	0	B/40-90 cm	1982	4.9	2	133	329	72	1	0.6
Cons.	66	B/40-90 cm	1982	4.8	3	106	322	79	1	0.4
Cons.	90	B/40-90 cm	1982	5.0	3	117	393	88	2	1.1
LSD (0.05)				NS	NS	20	NS	NS	NS	NS

Table 5—Soil test status of a Norfolk sandy loam prior to imposing tillage and residue removal treatments.

Horizon	Depth	CEC	Water pH	Mehlich I extractable P	K	Ca	Mg	Mn	Zn
	cm	cmol(p^+)		mg kg^{-1}					
Ap	0-20	1.8	6.0	53	71	273	36	11	1.7
E	20-40	1.8	5.7	7	66	186	35	3	0.4
B	40-90	3.9	5.2	4	87	297	74	1	0.2

Water conserving merits of conservation tillage and effects of residual corn stover on subsequent corn yield were most evident in 1981. Total rainfall during June, when anthesis occurred, was only 23 mm. Therefore, any increase in water conservation increased grain yield. Data in Table 3 show that without supplemental irrigation water, grain yields in 1981 were significantly lower where 90% of the stover was removed in 1980 than where all residues were left on the surface. However, grain yields from all conservation tillage treatments exceeded those where all residues had been incorporated by disking.

Data in Table 4 show the percentage of soil surface covered with corn stover one month after grain and stover harvest. Undecomposed pieces of this material plus dead winter weed species provided soil surface cover the following season which decreased surface runoff, reduced evaporation, and increased rainfall infiltration. Tensiometer data (not published) also showed that profile water content from anthesis through grain fill was generally greater when crop residues were left on the soil surface than when they were incorporated. However, when soil water or plant stands were not limited, harvesting crop residues had minimal ($\leq$6%) influence on corn grain yields (Table 3). The influence of crop residue management practices on seasonal water balance and stand establishment in this experiment was similar to that found in other conservation tillage experiments with corn (4) in the Southeastern Atlantic Coastal Plain.

Harvesting crop residues significantly increased annual N, P, and K removal (Table 2), but the magnitude of increase was dependent upon season, water management, and percentage of stover harvested. Removal of K was increased most (49 to 124 kg ha^{-1}) because K concentrations in the corn stover averaged 1.5 to 1.9%. Stover N and P concentrations averaged 0.78% and 0.18% which increased annual removal of these nutrients by 26 to 57 and 6 to 14 kg ha^{-1}, respectively. Secondary and micronutrient removal were not substantially increased by harvesting corn stover. Harvesting rye in 1980 increased N, P, and K removal by an average of 24, 4, and 30 kg ha^{-1}, respectively, but this practice was discontinued. Therefore, it contributed very little to changes in soil nutrient status during the 4 years.

Analyses of soil samples collected when this experiment was initiated (Table 5) showed that extractable P was high; K, Ca, and Mg were medium; and Mn and Zn were adequate for corn production in the Atlantic Coastal Plain (8). Subsequent analyses showed that most of the statistically significant changes in extractable nutrient concentrations occurred in the upper 5 cm after lime was applied in the fall of 1980 (Table 6). Concentrations of Ca, Mg, and Zn were significantly greater in this increment when conservation tillage practices were used than where crop residues, lime, and fertilizer were incorporated by disking. Phosphorus concentrations showed similar trends, but differences after 4 yr were not statistically significant.

Surface stratification of nutrients when reduced tillage is practiced has been documented (2,9,27), but in the Southeastern Atlantic Coastal Plain cation stratification is less permanent than in Midwestern loam and silt loam soils. Coarse-textured soils in this physiographic region have low exchange capacities and receive sufficient rainfall to leach cations into subsoil horizons. Movement of K illustrates this best because, unlike Midwest data (12), K concentrations in Atlantic Coastal Plain soils are frequently greater in subsoils than in surface horizons. Interactions among K, Ca, and Mg ions (23) result in leaching of K to Bt horizons regardless of fertilizer placement. In this experiment, extractable K in the Ap and E horizons was not changed after 4 yr (Table 6), but it was 40% greater in the Bt horizon.

Surface pH (0–5 cm) was significantly different only in 1982, when under conventional tillage, it was lower than under conservation tillage with or without removal of crop residues (Table 6). This result differs from many conservation tillage experiments where nitrification of surface-applied N and decomposition of residues significantly decreased pH in the surface 5 cm (2,21,26). In this experiment, however, sidedress N was provided by injecting anhydrous NH_3 approximately 15 to 20 cm deep between rows of corn. This method of sidedressing N did reduce subsoil pH, although not differentially among the four tillage/stover removal treatments (Table 6). After 4 yr of continuous corn, average pH values in E and Bt horizons were 0.5 and 0.3 units lower than when the experiment was initiated (Table 6).

Harvesting crop residues for 2 yr significantly reduced K concentrations in the Ap horizon in 1980, but in subsequent samplings, differences at this depth were not significant (Table 6). Following the 1982 growing season, K concentrations in the Bt horizon were significantly lower where crop residues had been removed for 3 yr than where they had been returned. This apparently reflected the lower amount of K available for leaching because there still was a net increase of 20 to 30 mg kg^{-1} compared to initial soil analyses (Table 5). These results indicate that if adequate quantities of fertilizer nutrients are applied to compensate for increased nutrient removal, harvesting crop residues from these soils will have no significant effects on soil pH or extractable nutrient status.

Chemical analyses of ear leaf tissue showed few significant differences in plant nutrient concentrations because of tillage system, water management, or crop residue removal. Applying dolomitic lime between the 1980 and 1981 growing seasons increased soil pH in the upper 5 cm which decreased ear leaf concentrations of Mn and Zn, but not below critical levels of 15 mg kg^{-1}. In general, all measured plant nutrient concentrations were within normal sufficiency ranges (15,22).

SUMMARY AND CONCLUSIONS

Harvesting 3 to 7 Mg ha^{-1} of corn stover from a Typic Paleudults in MLRA 133 could provide 5 to 11 $\times 10^4$ MJ ha^{-1} of on-farm bioenergy each year. Provided conservation tillage practices are used, this could be accomplished without reducing soil cover below 80%. Harvesting crop residues increased annual N, P, and K removal by 26 to 57, 6 to 14, and 49 to 124 kg ha^{-1}, respectively, but secondary and micronutrient removal was increased only slightly. Extractable soil nutrient concentrations were not depleted because fertilization programs compensated for increased nutrient removal.

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